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The Fourth International Workshop on Structural Health Monitoring was successfully organized at Stanford University on Sept. 15-17, 2003 under the sponsorship of the National Science Foundation, the US Army Research Office, and the Air Force Office of Scientific Research.

The objectives of the Workshop were to:

- review the progress of the current rapid development in technologies related to the field;
- identify key and emerging issues in research and development, and;
- promote exchange and cross-fertilization across many disciplines (sensors, sensor systems, networking, computing, data mining, diagnostics, prognostics, signal processing, multifunctional materials, etc.) and applications (ground/air/space transportation vehicles, missiles and launch systems, civil infrastructures, and marine structures.)

Distinguished individuals from industry, academe, and government were invited to deliver keynote lectures and presentations

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The Fourth International Workshop on Structural Health Monitoring

Stanford University, Stanford, CA

September 15-17, 2003

Final Report for the period 8/15/2003 – 12/31/2003

Grant No. F49620-03-1-0419

Submitted to

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Summary

The Fourth International Workshop on Structural Health Monitoring was successfully organized at Stanford University on Sept. 15-17, 2003 under the sponsorship of the National Science Foundation, the US Army Research Office, and the Air Force Office of Scientific Research.

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Distinguished individuals from industry, academe, and government were invited to deliver keynote lectures and presentations. Keynote speakers included:

Bruno Berali – Airbus
Dan Frangopol – Univ. of Colorado
Patrick Goggin –Boeing Phantom Works
K.P. Kress- EADS, Germany
S. C. Liu- National Science Foundation
Udo Peil – Technical University at Braunschweig, Germany
David Pratt - US Air Force Laboratory
Nobuo Takeda – University of Tokyo, Japan
Shawn Walsh –US Army Research Laboratory

The workshop also attracted many companies and institutes who participated in the Product and Technology demonstration Session, where 18 companies displayed their products in booths. Participating companies included:

Acellent Technologies, Inc.
EADS
Boeing Company

Wright-Patterson Air Force Laboratory
Analatom Inc.
BAE Systems
Digitexx Data Systems
EXFO
IFOS
Intelligent Optical Systems, Inc.
Jentek Sensors Inc.
LXSIX
Micro Optics
MicroStrain
Motorola Company
Physical Acoustics Corporation
Smart Structures
Structural Health Monitoring Systems
Sage Publications

Each day the workshop concluded with a panel discussion on key issues and concerns in three areas - aerospace/aircraft, civil infrastructures, and general applications. An original transcript of the general application session follows. A proceedings of the workshop, a collection of all technical papers presented at the workshop, has been published. More than 350 researchers, managers, faculty, and students from around the world participated the workshop.

At the workshop, two structural health monitoring awards were established - the Lifetime Achievement Award and the Person of the Year Award.

SHM Lifetime Achievement Award

At the workshop banquet on September 15, 2003, an individual in the SHM community was presented with the inaugural *SHM Lifetime Achievement Award* for meritorious accomplishments in research, technology, education and service over their career.

The prestigious Award is a newly established effort to recognize the outstanding contributions of individuals in SHM throughout their career. The evaluation criteria of the award focuses on the overall *impact* of the individual's contributions in the form of research, technology transfer, education and service. The Award Selection Committee consists of faculty members from academia, industrialists with a broad view of technology and researchers with the ability to assess the commercial impact of technology. The Committee receives nominations each year from the SHM community. The Committee selects the winner who receives the award at either a European or International Workshop on Structural Health Monitoring.

SHM Person of the Year Award

Another award presented at the workshop banquet was the *SHM Person of the Year Award*, presented annually to individuals in recognition of their recent outstanding contribution to the field of SHM. Contribution can be in the form of theory, analysis, applications, education, or other methods that potentially benefit society.

The *SHM Person of the Year* is selected by the editors and associate editors of *Structural Health Monitoring: An International Journal.* A plaque provided by Sage Publications is presented to the awardee at either a European or International Workshop on Structural Health Monitoring. This is another newly established award. This year it was presented by Mr. Christopher Hall, Publishing Editor - Sage Publications.

Dr. Chuck Farrar was the recipient of the Lifetime Achievement Award, and Profs. Doug Adams and Victor Giurgiutiu received the Person(s) of the Year Award.

Major topics of the workshop include:

Sensor Technology
Fiber optics, piezoelectrics, shape memory alloys, microelectronic sensors, nano sensors, smart sensors, wireless sensors, etc.

Sensor Networking and Systems
Distributed sensor network, sensor network optimization, sensor embedding technologies, local/global signal processors, wired and wireless communications, etc.

Signal Processing and Diagnostics
Data mining, signal interpretation, innovative damage and corrosion detecting techniques, identification methods, real-time processing monitoring techniques, nonmechanical in-situ characterization, modal and nonmodal analyses, neural network technologies, generic algorithms, inverse solvers, etc.

Prognostics

Statistic and/or deterministic prognostic techniques based on sensor measurements, residual stiffness and strength prediction, modeling and computation, etc.

Integrated Structures

Innovative manufacturing and processing techniques for integrated structures, remote sensing system, durability and reliability of embedded sensors and sensor networks, robustness of integrated structures, etc.

Economic/Safety/Social Impact

Cost reduction analysis in field maintenance, material/structure tests, safety and reliability assessment of critical structures, evaluation of design benefit based on SHM techniques, etc.

Applications

Aircraft and missile structures: Helicopters, airplanes, engines, motor casings, etc.
Space structures: Satellites, space stations, reusable launch vehicles, etc.
Land/marine structures: Automobiles, submarines, ships, etc.
Power/utility facilities: Power plants, overhead/underground facilities, remote transmission facilities, etc.
Civil infrastructures: Bridges, highway systems, buildings, etc.
Biomedical implants and devices

A transcript of the discussion from the General Applications Session

Panel Discussion: General Applications
Kresge Auditorium

Moderator: Christian Boller – University of Sheffield
Joerg Kumpfert – Airbus
Nong Chen – Caterpillar
Chad Lensing – BP America
Anthony Allen – Motorola
Steve Arms – Microstrain
Paul Ruffin – US Army
Abdulrahman Al-Khalidy– General Electric
K.C. Park – U. of Colorado at Boulder

Wednesday, September 17, 2003
14:50-16:10

Christian Boller:

My name is Christian Boller. I came from the University of Sheffield in the UK. There are still a few people around here, which I think is quite good. I am happy that all the panelists are here. I hope that we are going to have a slightly lively discussion here. We are talking here about general applications.

So you see the aero-space side is still represented and the civil engineering side is represented somehow, but we have also representatives from other applications and I think that is quite valuable to see that it is not just aerospace and civil engineering. We are going to talk about general applications, about the key technology barriers specifically to get these things introduced here, and, of course, the cost benefits which are the things which are finally driving the whole thing and you see I have made then a slight distinction here in a second block so the question of the focus for research, the technology implementation into various engineering disciplines, and then at the end we definitely want to know the visions of our 6 panelists here. So with these few words I just want to open to each of the panelists with just 3 minutes given. I am trying to look at my watch so that we keep to that time and that we then go into a dialogue here with the audience. So I think we should just start here at the beginning. Yes, I just have to mention here a few technical things. There is one new person here who is Abdulrahman

Al-Khalidy, who is from General Electric Research. He is coming instead of the representative from Lockheed-Martin [Suraj Rawal], who couldn't make it to come here. The other thing is, yes, you are already very well seated – You will possibly be able to see if the one or the other slide is shown on the front and afterwards if you are going to ask questions, if you could, please come to these microphones here, because everything is recorded. So it makes it easier to record your question properly. All right, thanks a lot, and I will start here with our first representative. I think you will mention your name, etc.

Chad Lensing:
I have a few slides to show. My name is Chad Lensing. I work for BP America based out of Houston, Texas. The type of work that I am involved in is offshore exploration and production, especially in the Gulf of Mexico. The first slide I have up here is some of the structures that we work with. You see, these are all BP platforms that have been constructed and installed and are producing oil. And then we have our platform that we are building right now which is Thunderhorse and which are the 2 pictures below. What you don't see on these slides is all the stuff that happens underneath the water and that is where I get involved in the structures that sit below the waterline all the way to the seabed. Some of the applications – and I came here with one specific application in mind and that was the monitoring of risers, which is basically the pipeline that hangs off the platform and reaches to the seabed. And the 2 areas of our concern in terms of fatigue is near the top section near where it hangs off the platform and the touchdown point. Currently we do not do any structural health monitoring in the sense of monitoring or detecting damage, detecting cracks. We don't have very good measurements for corrosion that would occur in these pipelines. What we do monitor as part of our integrity management program is we do measure vessel motions using acoustic Doppler type sensors. We do use accelerometers to measure the motion of the riser itself, but for the most part, like you said, we don't do any structural health monitoring. And that is something that we are very interested in especially. I think that I can say that for the oil industry offshore structures, that this is particularly one application that we are very well interested [in]. One of the reasons is that some of the things – events that occur out in the Gulf of Mexico, such as when we go to design for extreme events like hurricanes, 100-year storms, 10-year storms, installation in deep waters of 5,000 to 10,000 feet of water depth, there are a lot of things that can go wrong. Also, things that may get dropped – heavy objects that get dropped onto pipelines.

Christian Boller:
Can you also say something regarding the technology barriers?

Chad Lensing:

Oh, yes!

Christian Boller:
It is a nasty task the question, I think, and regarding the cost benefits?

Chad Lensing:
Some of the technology barriers, because we are new to this, that we are trying to evaluate different types of sensors. The type of environment as I described before, 10,000 feet – I don't want to say inaccessible, but very difficult to access and do inspections. We have issues of subsea hardening, meaning 2500 to 5000 psi hydrostatic pressure. We have reservoir temperatures that go up to 300° C, 10,000, 15,000 psi.

I would like to invite you to come to the oil companies and see where your sensors can provide some monitoring in those types of areas.

Christian Boller:
Can one somehow conclude that you definitely have a cost benefit here?

Chad Lensing:
Yes, we do have a cost benefit. One thing is the better we understand the riser performance and the more information we know, the better decision we can make. The cost benefit is that we want to prevent any kind of shutdown in production. And if you think about a platform that produces 40,000 to 50,000 barrels per day and we have to shut the platform down for 2 weeks to install a new riser or something like that or do repairs. So I will let you guys figure out the matter on that, but today's costs dollars per barrel are about $27. There is a significant cost savings and there are others besides cost that we consider and that is, we don't want to have any catastrophic events, of course, save lives, and also we don't want to have any oil leakage into the sea.

Christian Boller:
Good! Thank you! Let us switch over into the air, into the aerospace. We have had it before, but maybe you can summarize it under that view.

Joerg Kumpfert:
Thank you very much. I have the pleasure to join the panel discussion the second time so for those who have been here on Monday, please do not expect too many different things from my comments on Monday. My name is Joerg Kumpfert. I am the chief technologist on structures of Airbus in Toulouse. In this role I have to oversee the whole R&D activities of Airbus and my colleagues, the whole R&D program. So I am not an

expert in SHM absolutely, but more interested in the strategic aspects and the technology behind where to go and when to go. To the questions, where are we going to use it, there are major applications. For instance, we are interested in advancing our lab testing. We are interested in off-line and on-line testing, as was presented by different colleagues during various sessions from Airbus Germany, France, and in España [Spain]. In the question, how–

Christian Boller:
Technology barriers?

Joerg Kumpfert:
Not technology barriers. First applications. I think in Airbus we have a very good experience with the step-by-step introduction of new technologies, and a good example here is the introduction of composite materials over the last 25-30 years. Each new component was built up on the experience we made with the previous component, so that at the end we did not start with something like the centering box or the pressure bulkhead we are now using in the A380.

I see a similar strategic scenario also for the structural health monitoring, which is advancing quite a bit. We could see here in this conference so it is very likely to start with a low risk approach and to gather experience. since reliability is at the end the most important factor to take fully advantage of SHM, so starting with some low-risk applications where we may reduce maintenance costs. What we need to identify is the immediate benefit for our customer. The next step is maybe also quality assurance during manufacturing, which is a very attractive area, and maybe also helpful in order to gain experience in that area. And then last but not least based on this experience, there may be the chance to take advantage of the real–the benefit, which is weight-saving, but then, of course, it will be very important to make sure that the whole system is reliable [in the] [various] areas. One important thing in this scenario, these major three phases will be, of course, to understand better the cost-benefit ratios for the different sensor systems. And this will very much depend on the individual component and the individual application. At the end we have to increase the availability of our aircraft to decrease the life-cycle cost and to increase the performance. But in this order, so just increasing the performance and to forget the rest will not work. Cost benefit which is an outcome of that in the area of maintenance as also presented in the presentation by Bruno Berali on Monday, it's clearly a lower benefit. The highest benefit is clearly if it comes to the possibility to take advantage of the design benefit. But here we need to gather the experience.

K.C. Park:

I am K.C. Park from the University of Colorado. I am the singleton from academia in this panel. In the general applications, let us think about, say, car maintenance. Did you know, car maintenance is the major profit source for the car dealers. In fact, some of the dealers make more profit in maintenance than in selling cars. So when you look at the dashboard of any typical, even a 2003 or 2004 model that is coming up, there are only about 3 or 4 sensor outputs in front of you. It says change the oil, at the mention there is 10,000, there is a 90,000 set to a, and there is an oil level and a fuel gauge level. The reason I am pointing out is that this is so obvious to us, but there is a subtle cultural resistance about society in general investing in maintenance rather than just the selling of a new product. If we were really serious about, for example, health maintenance, really, our human maintenance, our government would spend lots of money on health maintenance rather than the hospital emergency room, which is very expensive.

So from the educational point of view I think the cultural barrier is probably the major issue in general rather than the cost benefit area. One thing I would like to mention, it's in the previous 2 panel discussions, it looks like there is a casual assumption that the educational community will provide all the necessary manpower to you folks, who just hire these people at the snap of your fingertips, and you just get on with your business. I am not really too sure whether this is really well communicated to the educational community or you don't need any special educational programs that would support this kind of activity, because right now when you survey at least in the United States, there are only a very few, handful [of] institutions that are involved in the health monitoring research, and I am not sure whether that is knd of level of manpower you folks need in industry or whether we need expanded educational support for you guys. Relating to that, I have been spending the last couple of years to identify what I consider the basic research issues associated with health monitoring systems. Of course, the underlying education in dynamics and controls and instrumentation and the multi-disciplinary approach. Things of that nature will support these activities.

However, if you really sit down and look at it, I think this community needs to make a clear message to the academic community, what it is they regard as basic research issues by the academics, so that we can work hand in hand. And I am not too sure that has been clearly presented to the academic community by the industry and the user communities. Finally, there is a tremendous equipment cost associated with the electronic manufacturing communities. This is a huge business, because every time when you lay out new chips, new electronic products, you have to make a–the electronics industry has to make a tremendous investment. The mode of operating so far, they just keep producing a new equipment for the new product lines, similarly for the car manufacturing. I don't know how far the industry can actually sustain this type of capital investment for what appears to be a global competition. So instead of just the health monitoring, the performance monitoring capability that would ensure some of this very expensive manufacturing facilities could support the multifunctional manufacturing capabilities.

Christian Boller:
Good! Thanks a lot. I think that is a very good view from the academic side. All right! Next!

Paul Ruffin:
Thanks! Good afternoon. My name is Paul Ruffin, and I am from the US Army Research Development and Engineering Aviation and Missile Center, and I will address an application associated with the military I should say instead of just the Army. And we are talking about weapon systems, health monitoring for missile systems. So, what is so unique about missile systems? Well, you build a missile, and in the past you store it in different regions, cold, hot, whatever, but the missile has to work whenever you need it–10 years, 20 years or whenever you need to use it. And just recently, the way we have regional conflicts now, they are short-lived. So that means that these missile systems or subcomponents will have to be transported. So we need to have a way of determining whether or not the missile systems and their components will work after being transported or stored in different areas. Today I want to bring up one component of the missile that is very critical and that is the rocket motor, the rocket motor and the propellant grain. The rocket motor consists of the propellant grain, but it has a casing, and that casing is a multi-structured casing, and you have this bond line between the propellant grains and the other parts, the insulation for thermal insulation and things like that.

After aging or being in different environments, vibration shock, something could go wrong. Presently, currently, we do not have a good way of noting whether or not the propellant grain, one, whether or not the chemical integrity is still intact or the structural integrity or of the bond line. So we would like to be able to come up with a way of embedding a seamless sensor in the bond line. To be able to determine the structural integrity of the bond line as well as the chemical integrity of the propellent. Another area has to do with the early battlefield damage assessment and situational awareness and in that area we could use autonomous sensors to give us information early on, and the last thing here is what we will call conformal missile scans where we can use –scan different types of–Well, in the [unintelligible word] [monster?] case of devices you can have a conformal scan for the result to control the air boundary flow and things like that along with a whole lot of other things as well as measuring the structural integrity of the surface.

I would like to address where the key technology barriers [are]. In the case of the rocket motor which I will put as the high priority here today, noninvasive bond line measurement or sensor that will not have those ridges like normally you have these. With the new materials like metal technology, metal-carbon materials, or whatever way the material is and whatever solution, we would like to have a composite structure. The barriers are seamless, non-invasive bond-bond material. I would say that is one the major barriers. Another barrier is that we would like to be able to measure outside a metal case. And I think you heard Steve Marote talk this morning about a program called Remote Readiness Access Prognostic Diagnostic System–RRAPDS, where we are using different temperature sensors, humidity sensors, and even chemical sensors and other sensors, vibration sensors, to measure the environment, where we can look at condition-based maintenance versus proactive maintenance or time-based maintenance or corrective maintenance. Those types of maintenance are more expensive and if we could use the RRAPDS program, small sensors, that would have to have low power and the power needs to last for quite a while – 10 years.

Christian Boller:
Do you have anything to cost benefits? Just a 10-second statement?

Paul Ruffin:
Cost-bound benefits? If you ask me, it is the condition-based maintenance. If you would–You can save by noting which missile will fail, you know, predicting which one will fail, unlike what we do now, is go in every so often with the preventive and just pick out so many and test and see how good they are. Or if you have a problem, the corrective maintenance, you know, you go and have to figure out what went wrong. But with this, that is one, but then reduce logistics, because you know what the good ones are–you transport all the good ones and then you will have increased lethality also, because, of course, you just have the good results. You know the ones that will work.

Christian Boller:
Good! Thank you! Let's go to the gentleman.

K.C. Park:
Let me just add the cost benefit issue in academics. We have a 2 infinity unknowns. If you look at it from the industry point of view, the cost divided by benefit is infinite. But

if you look at it from the academic's point of view, the benefit divided by cost is also infinite from the academic point of view.

Christian Boller:
OK! Thanks!

Abdulrahman Al-Khalidy:
Good afternoon. My name is Abdulrahman Al-Khalidy. I work with GE Global Research Lab out in Albany, New York. I was just asked two hours ago by Fu-Kuo to be here. I don't know whether this was a reward or perhaps more of a punishment. Perhaps it was the question that I asked two days ago. So I ask you to be merciful when you are questioning. I am also happy that I am replacing Lockheed Martin, which is one of our competitors. So one more win for GE! My work in health monitoring started in my early days in graduate school back at Cornell. I worked in health monitoring of structures. I remember that I was so excited about the detection of the reduction in stiffness, and I was bragging that we could detect or we could know when stiffness is reduced by less than 1%. So when I went in my first internship with GE and I told this to someone there, he said, "One percent? So what? So what will happen to the structure? Will it still survive?" And I said, "Yeah, most likely it will." He said, "So why do you care about this 1%?" And he gave me the idea is that you have to get a balance between.

It is good to detect damage, all right, but it is more important to the end user to know what will this damage mean to them. Will this mean that the structure or the motor or the blade will fail and if it will fail, how fast will it fail? So the prognosis part of the health monitoring is much more interesting and important to the end users in a lot of cases. One area of structural health monitoring we use, you know, a lot of companies do farm out a lot of products and components and we need at some point to choose between 6, 7 suppliers of a certain component, and usually the way you do this, you put these components, you get these components from these different suppliers, and you put them under accelerated life testing and see which survivies longer. In some cases this takes a long time, so one issue which was important for GE industrial systems is whether we could reduce this time from say, 1 year down to a few months. Still do the accelerated life testing, but be able to deduce damage indices and do again prediction based on mean time to failure. The cost benefit: Just shutting down one turbine engine unnecessarily is a lot of millions of dollars over the years. Detecting false positives is a big disaster. No, not detecting a crack and being reliable on our systems. If we want to say I have a structural health monitoring system that is there. It is bad to have a false positive, because this will reduce the credibility of your system. But not to be able to detect a crack is disastrous. So, the money, this cost saving is huge in turns, especially if we are talking about power systems.

In terms of aircraft engines you cannot put a price limit on it, a disaster is a big disaster. You cannot have a little disaster.

Christian Boller:
Where do the technology barriers figure in? If you can just bring yourself to that point?

Abdulrahman Al-Khalidy:
I think in going from the diagnostics to prognostics, I think this is an ill-considered question. It is a very complex question and so far the way you–My feeling is that the way to tackle this problem is to do more of statistical analysis. We have to introduce more of a statistical based approach in order to get prognostics. This is to me the only way to move forward. From detecting the damage and to be able to assess how severe this damage is.

There are also some cultural barriers. When we talk with end users they are more conservative in terms of what they want to use. If they use this device for 10-20 years unless they see that your new idea really does work and it gives results, they are not going to use it. Another barrier: In talking about localizing damage, the only solution we have is to distribute sensors, but with distributing sensors, putting a lot of sensors, the question becomes nobody wants to put all ofthese sensors everywhere. There is an issue of weight, there is an issue of mass, there is an issue of cost. Not everything that you transmit in all conditions will be reliable. Thus, you might be prone to some errors and these errors will lead to wrong diagnostics or prognostics.

Christian Boller:
OK.

Abdulrahman Al-Khalidy:
Thank you.

Christian Boller:
Thanks a lot. Let us go to the next!

Steve Arms:
Hello, my name is Steve Arms. I am from Williston, Vermont. I am from a firm called Microstrain. I want to thank everybody here in the audience, because I know it is the end

of the meeting and many of us have to catch an airplane and get home. Our firm produces a range of wireless sensing products, including wireless displacement sensors, accelerometers, strain gauges, thermal couples. The technology barriers that we face, particularly for civil engineering applications. It would be a big help to us, if there was widespread high speed cellular phone service in this country. The other barrier that we are trying to overcome through technological development are batteries that need no maintenance. In other words, take available power or energy sources, solar power, thermal electric, piezo electric, vibration energy, strain energy, convert that into a rechargeable battery that can be recharged in an infinite number of cycles. Thank you!

Christian Boller:
OK! Thank you! Then?

Nong Chen:
My name is Nong Chen. I work at Caterpillar. We make mining construction equipment. We are also one of the largest engine makers in the world. I am also here as a program manager for an NS [?] AVD product called Shield. I think some of them have probably seen a demo yesterday. What we are trying to develop in this program is a system that makes our structure intelligent so it can feel what is happening in real time and think and decide what it is supposed to do. In terms of technology barriers, if you look at the technology component level, the sensor we are developing which we are working with [unintelligible] [automaton] has to be very low energy because we cannot expect the operator or whoever is operating at the mine site to go and change the battery every day or week or every month in that manner and it has to be reliable and for the wireless network that Motorola is developing [and] has to be low energy, too. And also it has to be able to transmit signals at the data rate we require. And keep in mind that the structure we are talking about could be three stories high and 30 meters long and the bucket is lifting–Every bucket is 40 tons of rocks and operating in a very unpleasant mine site environment.

So this all poses challenges for the wireless network. And then the brain box we are developing which native American technology has to be able to think really fast in real time, handles very complicated algorithm[s]. So all those technology components are challenges, but my opinion is that the number one challenge for technology barrier, especially for–put it on the product for our end users is reliability. The system has to be reliable. Even our own business unit will tell us, say, right now one of the number one issues with performance or reliability is already on the electronic side. So if you are adding something and it is not staying at the least at current reliability level–not alone I believe that is not only for our product, but that is for other products. How can you convince the end user – the customer – the operator to actually use that product so I think the number one issue is reliability.

In terms of vision, I think I learned a lot of things in this meeting. Essentially the structural health monitoring system I believe is an information gathering system. It builds infrastructure for gathering information so you get data and one of my collegues likes to say, "OK, you get data and you translate it into information and you generate knowledge and decide what action to take." And then I would like to close that loop and say when are you going to take that action if you know what is the right action to take. So we have been thinking about—I saw a few presentations I would like to talk about like real-time feedback controls, adaptive monitoring, so I think that is one of the next steps and also talk about, let us say, if you know the right action is to heal the structures, so what is the possibility to heal structures in real time? Like self-healing structures. I think that is getting into the multi-disciplinary topic here. That involves systems and control people. That involves material scientists. I think those are also very promising areas to talk about.

Christian Boller:
We are just coming to the vision I think even a little later. I think you are already somehow we are going into the vision. Very briefly, do you consider for your point of view cost benefits high or low? Just use the one word or the other without specifying it.

Nong Chen:
I am going to answer that question around it, not directly. We are from ground [industry?]. I do not know how many people here are from ground. I know most of the people that are here because they have things that fly, but I see a lot of presentations all alike this issue about cost and value. That means I guess we are all facing the challenge of how to convince our customers to add the system to their existing product and be willing to pay for it. I would say that is an issue for us, too, even for our own business unit. But my thought is we might have to step back and think about whatever we are building can bring to us. What's the value? It may–The biggest value may be in the structural health monitoring itself. Or maybe beyond or maybe for some totally un—We haven't thought about application, because we are essentially building infrastructure to transmit or gather information and share that information so there could be a broad market for utilizing that and commercialize that – Information essentially is a product, and I think that across industries that a collaboration can really help achieve that commercial value.

Christian Boller:

OK. Good Thank you! So let us hear to the end in three minutes what is NSF's view. NSF?

Anthony Allen:

The last but hopefully not least. My name is Anthony Allen and I work for Motorola. We are one of the labs, a particular research arm of Motorola. We are wireless people, not necessarily structure health engineering, structural health monitoring, so a lot of this stuff tends to be a little bit off my plane of comfort. I am glad to see that there is someone from Cornell on the panel, so that I have at least something in common with somebody here. But we have been looking at wireless sensor networks for the past 5 years or so and structural health monitoring we stumble on the fact that our networks could be useful in structural health monitoring. But so far as applications, there are a lot of other applications for wireless sensor networks. Touching a few, for instance, in agriculture, I think I wrote down a few here, even in human health monitoring—If you want to put sensors in a human—do something wireless there.

In the military, which is where the wireless networks actually started, they have a number of applications there. So I guess I am a little off subject. Those are not particularly structural health monitoring applications. As far as barriers, though, I can see that for wireless networks within structural health monitoring I can see quite a few that we are tackling hopefully within this project. Now I will mention that a lot of times the environment can be a huge barrier. In terms of the large metal structures, I am an RF guy. So RF—Not many wireless things like metal. Actually, none of them do.

What else? Energy. Someone else mentioned energy harvesting. That is a big thing for us as well. Batteries have to be replaced even if it is only 2-3 years down the road. So we would really like to be able to harvest energy from the environment. One that we are experiencing a good deal of dealing with on the NIST project that we are working on together with Caterpillar [and] Automaton NE Tech is a kind of a data rate versus power and cost tradeoff that we have to deal with in the sense that wireless networks, if you want to get higher data rates than most networks, but especially wireless networks. If you want to get higher data rates, you are going to pay for it pretty dearly in terms of battery life and in terms of cost of devices. So we tend to go to lower data rates. Now if you have lower data rates, yes, you can have longer life and lower cost. But then you have to deal with how do you get all the data or do you have to do some local processing. Things like that so it tends to grow or expand very quickly. So [those are] some of the barriers that we have yet to deal with and we are trying to deal with in this project in particular.

Christian Boller:
OK. Cost benefits? Maybe just a word?

Anthony Allen:
No wire! That's a big one. And maintenance. No wire seems to be the big thing. Running wire can be very expensive. That's it.

Christian Boller:
Good! Thank you very much for all these statements. It was, or course, as usual longer than expected. You have heard I think a lot of applications here. You have also seen the barriers and there are hopefully some solutions so I would like somehow to whatever sort of applications which have been presented here and the technologies you possibly have available around here to ask the question, is my technology available? So I want to open regarding a little sort the focus of research also here to the floor and to ask specific questions here to our sort of potential clients, what is your technology? What should you really do to meet these sorts of requirements here? So, who wants to start first? Up here! Please, can you please step down to the microphone.

Mark Seaver:
I am Mark Seaver from the Naval Research Lab and what I as a developer, one of the big problems that I see even if I may or may not have the right technology for some of you out there, but the problem from my point of view, I need to see someone who is willing to pay the pretty expensive dollars that it takes to get something from the field test stage to the manufacturing stage. Because what I keep hearing is that the panel thinks the manufacturers want a device that's been proven—Maybe FAA certified or things like that, and yet to get it from the point where I have tested it on, you know, on an airplane wing out in the field or something like that to the point where it is a certified device is a slow, expensive process, and I don't see anybody who is putting up the money to do that.

Christian Boller:
Yeah! Can you see what money you are talking to get this qualified because otherwise that side could never respond to you if they would be willing to pay for it or not.

Mark Seaver:
Some of that depends on the requirements that you are shooting for. But as a kind of rough estimate, I would say, you are probably—We are talking about having one of our fiber optic systems flight-qualified for space vehicles and the kind of minimum number for that is around a million over three years and it may take a million and a half over three years.

Christian Boller:
No! No! Thank you! That is a sort of good number that will start a discussion here! So, who of the panelists want to make a statement regarding something like this? How? It was—As much as the aerospace industry, for, he was talking about space. It was not the Airbus.

Joerg Kumpfert:
Well, it comes close to my initial remarks. I believe it will—The key will be to select the right technology in the right area at the right time, whether or not this would satisfy you. If you go for the low risk approach, well, with also limited benefit, but also the money you need to invest is limited, so it will not be too difficult to find a sponsor and then this step-by-step approach will lead to [a] sponsor then of the most sophisticated systems.

Christian Boller:
Somebody else wants to comment? Maybe the Army has some takes in such a business.

Paul Ruffin:
I think we are almost alike! He is Navy and I am Army. I guess the difference is, do I understand you, you are actually testing parts, right!

Member of the Audience:
[There is an off-mike speaker who speaks at some length, but cannot be clearly understood because he is not at a microphone.]
We are field testing. We are testing fiber optics, and reliable but not —

Paul Ruffin:
Right! You know, that has been the hardest thing that I have seen. I have been working for the Army for 23 years. And that is the hardest part. The question is, How do we transition the technology? The best transitioning that I have seen is especially if the Army and Navy and Air Force, whoever would have an in-house program where they are developing the system. You know, the system down at the component level. If you are developing a system and you go out for the contract and when you write your contract if you put in your requirements and also as part of the contract, put in what you can put with your design or whatever which is most of the time these houses they were not used. If they would take that and consider it and there have been several cases in the Army where that has been done. One particular case, you have heard of the system called ATACMS. That is the Army Tactical Missile System, where in the contract there were specifications and things put in that would be along the lines of the technology that had

been developed and some of that was considered. But the big companies, the Lockheed Martins, the GEs, and all the Raytheons and whatever—They are the ones that the—what we call the PM, the Project Manager's Office, they look for them to qualify and they have their subcontracts in the different areas.

In the case of inertial systems—They have those contractors testing. We also have test facilities. We support those big houses in testing, but what those colonels look for is for the big companies to say this will work. This is part of the system. This is a system thing and it will work. That is what I have seen so far.

Christian Boller:
I want to thank you. I think those are very valuable comments. Maybe we will come back to the systems approach. Are there some other comments here from the audience? I think you have a good chance to ask here people who need applications, who need specifically the systems, the systems approach.

Abdulrahman Al-Khalidy:
Let me add one thing from a commercial point of view. Now, we work in the GE Research Lab and we work with all the GE businesses from aircraft engines to medical systems to NBC and all of the rest. A lot of times you set off on a project and you work on it on a component level and you don't bring on the whole systems approach and you would get good results, you would show them at the end of the year. But the business doesn't adopt that. I would say the only possible way, because at the end of the line any enterprise will look at the bottom line and they will look at their customers. If you have this customer who buys into this, that he wants that. There is a pull from the customer, saving money, saving lives, what have you, and you do this program as a systems approach where you include us who work with the businesses and pulling the customers in, you have a better chance at success. That is the working formula.

Nong Chen:
I would like to add a little bit. We are talking about a systems approach. I think we are lucky in the Shield Project that we have 4 companies doing each very, very important components. That would not have happened if it were not because of the government cost-share project. So in that sense it helped us financially, but more it helps bring the team together. So I think networking and leveraging is really important.

I don't know if it would apply to the Army application you are thinking about, but whatever other company who might have gone down that path in the past maybe in a different industry, whatever information you could be sharing or leveraging.

Another thought I have is when you start with application in mind, but during the process of achieving the those goals, what are the smaller things you could commercialize along the road that bings some revenue in, maybe for a totally different application, but I think that would help a lot too.

Christian Boller:

Is there somebody in the audience who can offer something which delivers a system. That is somehow a question which arises to me. Is somebody? We don't have anybody around here who is delivering a system. This is obviously an essential point here. I think so there are obviously people who are in the group and who are in the system, and there are people who are outside the system. So just seeing there is nobody here who is in the system, so we obviously have all sorts of individuals which some of those may lead to [the implication that?] the different engineering disciplines. So we have electrical engineers and materials engineers and whatever sort of sensor technologies, etc., which we somehow have to bring together to a system. What is maybe—Still the audience has questions. It is for me a question to the panelists, how can we bring together a system which suits you? Let us say, if you are just waiting to get one day a system and obviously there is no system here in the audience and you have a need and a cost benefit, how to organize that system?

Abdulrahman Al-Khalidy:

I think you have to start thinking on a system level. And I think this is the starting point. Let me give an example. I cannot talk too much about it, because this is a little bit proprietary. We are designing a new modality in GE medical systems and it is from the ground up. So usually when you do this you have a lot of components, a lot of engineers, in different parts of the world. And you have to talk to this guy and that guy and you make sure that everybody is online, everybody agrees. So [that is] what we did and this was at the beginning of the year. They said, OK, we are going to bypass those after we have talked to them, we are going to bypass those, go to the field engineers and after that we bypass the field engineers and we went directly to the customers. And I spoke to the customers directly in the hospitals, nurses, doctors, and I learned what they said and from that I went back to the field engineers and then back to the research engineers and back to the system level components. And now we were able to push this further. I think the thinking has to be system level.

Christian Boller:

But this is I would say sort of your development market research. So basically you have found the requirements which your market needs. But now you need to set together your system. You need to get your engineers so you may pick up people from here or from the conference. How would you do this?

Abdulrahman Al-Khalidy:
Is this question for me?

Christian Boller:
Sorry! No! I am just talking. You have given a good example and I think if we are talking about systems and we have various individuals who are in that field who come to this workshop, who demonstrate their things, who show their things, how can you harvest these things to get your system?

Anthony Allen:
I guess I will take a slightly different approach to him. What we have learned pretty quickly in this program when we are trying to develop a system where we have obviously 2 to 3 components that are kind of separate is that clearly defined interfaces are essential. And one thing [I think] that has approached us as Motorola does it and ended up trying to do these wireless sensor networks. Is that for example on the sensor side? As Motorola wanted to provide a wireless network, a wireless system, we consider that our system. But for somebody who is doing an application, let us say, a person in agriculture, they want to attach sensors, moisture [?], whatever, to our wireless devices. As Motorola, we may not want to take on that challenge. The market may not be big enough for us, but if somebody wanted to attach a sensor to our device, we would like to be able to provide them with some standard interface to do that which we are kind of lacking right now. 1451. I guess there is an ITP[?] standard. It is very heavy. Just light, easily understandable interfaces allows people to get together and take their piece and attach it to something else that is already available on the shelf We can put our VAS network out there on the shelf, but if nobody else knows how to interface to it or even how to use it, it just kind of sits there. So that is one way you can, if you can get together people in the industries and get together and put together clearly defined interfaces that allow the people to put the pieces together themselves that possibly could allow you to get all your systems together a little easier.

Christian Boller:
So what you are saying here is you are somehow leaving your interfaces open for other applications. Once you are—the Caterpillar solution—you may even use it for whatever, you may use it for the trucks or time saw[?], ships or something like this.

Anthony Allen:

Exactly!

Christian Boller:
Any comments? Well then, let us continue with the discussion. You have obviously some applications in mind. Now when you have these applications in mind, you should also have something like a sort of investment in mind, sort of cost for developing these things. Can you somehow from your different applications—Maybe we can start with the Caterpillar application here. What do you think would the development of such a health monitoring system cost for you. You don't need to give exact numbers. It is more a question, are we talking about a million? Are we talking about 10 millions or 100 millions. I am staying in a logarithmic scale here.

Steve Arms:
It depends. The answer is it depends.

Christian Boller:
Yeah! Which is it?

Steve Arms:
What is it that we are monitoring? If it is a rotating shaft, your entry point is quite low. You can get into that for less than a $1,000. And do a very nice job of it. If we are talking about the Golden Gate Bridge, then it is a completely different problem. So the system has to be defined based on the user's requirements.

Christian Boller:
No! I am talking initially about the development of the system, yeah, not about the purchasing piece.

Steve Arms:
I am sorry. The cost or development or the cost associated with the development. Well, the cost or the development and the cost associated with that development? I guess I didn't understand your question. If you—

Christian Boller:
Well, you must see a problem. You must see a cost benefit. Yes? Into that system that I get it and for a certain price.

Steve Arms:

But we don't make that investment. We ask the customer who has the problem to make that investment. We get money and we solve the problem.

Christian Boller:
Yes! So possibly you should ask your neighbor—

Steve Arms:
OK, and the way we do that is we wrap it up around nonrecurring engineering and then recurring costs and if those price payments make sense for that customer's problem, we get money.

Christian Boller:
Yeah!

Chad Lensing:
Just from the offshore industry, I think if we specifically look at risers and install them in deep water, it costs us roughly 7-10 million dollars to install a riser, the construction of it, the fabrication, the installation. If we compare that to the cost for health system monitoring and the consequences of having to shut down production in that riser. we tend to—We feel that that benefits us in those terms, we set aside a lot of funding and time commitment to develop that product. What the developers—and just to give you a number, a million dollars is such a small fraction of what it costs us to build an offshore structure. So if it means the health monitoring system providing the reliability to the integrity of the risers, then it is a worthwhile investment for us.
With the developers—Just some of our experiences with the developers and contractors that we work with is that initially we want to plant some seed funding and if we see this as creating a market for the oil industry, then that is something where we would take those initial results and share them with other oil companies, other service companies to the oil industries and we often do joint industry-type projects or have a joint venture in forming a company.

Christian Boller:
Thank you!

Abdulrahman Al-Khalidy:
I will give you a few numbers on a project that I am associated with. It deals with inspection and maintenance of rotor blades for GE 9-F engine turbines.
Usually this is done manually. It takes probably 2-3 weeks to finish, and if we were able to do this in a faster way, the cost or the savings was around 25 million dollars a year and

service costs and for that GE invested 4 million dollars for a complete from ground zero up automated robotic inspection and maintenance system. This is a figure

Christian Boller:

Any other comment? [Looking towards the audience] Yeah! Yeah! Please!

Jeff Sundermeyer:

Jeff Sundermeyer from Caterpillar. I want to address your question. I think you were asking about the cost to Caterpillar of creating a structural health monitoring system for, say, a vehicle and then talk about what the benefits might be. To develop a comprehensive structural health monitoring system for, say, a large wheel loader, on a logarithmic scale the cost is going to be 10 to the 6 point something, it is into the sum several millions of dollars. That is roughly the cost of the Shield Program, basically. As far as the benefits, I think we've got to remember that the benefits don't come just from detecting flaws and condition-based maintenance and things of that sort, but the benefits also come from the information from the system that gives the user day to day hints on how better to use the machine to get more dirt moved, make money faster. And if you can just improve their productivity by just 1%, then the structural health monitoring system ays for itself, because the cost on each machine is only going to be into the 10 to the 4^{th} dollars.

Christian Boller:

OK. That was it? Thank you very much for these numbers. Any comments from here? If that is now the case, maybe I have a question regarding the point you have made here. Have you based your estimate, your logarithmic estimate, on technology which is already available? Or how would you make that strategy to possibly how this technology which is already available, which you can use, basically combine things to make synergies. Because if I look back where certainly we spend more than that sum in the past for the developing of structural health monitoring, but what is the target? Can we somehow optimize the process to meet these different needs which have been expressed here? Does somebody or do you want to comment on this? Yeah?

Joerg Kumpfert:

My feeling is that you are coming back to the question we discussed 5 minutes ago. It is how to develop this kind of technology and how to translate new ideas into real applications.

Christian Boller:

Yeah!

Joerg Kumpfert:
Just a general remark. It is not my feeling that this is so different as in many other technical areas.

Christian Boller:
No.

Joerg Kumpfert:
I think at the end we need a top down approach and a bottom up approach. The top down is—Why don't we start the other way? I think that structural health monitoring is not mature yet. That is the reason that more and more scientists are entering this research area. On the other side, it is not brand new. So many technologies are available. So it is time to define the requirements top down from all end users, from all business users, to really understand the requirements which are quite different in aviation, aeronautics, for construction of vehicles and so on and so on. On the other side really to give the right answers, solutions from the research community and then to select together the best way forward in order to avoid dead ends.

Christian Boller:
How do you think these requirements could be expressed in a way that people get an access to this, because it is difficult to find out what you need and the Army needs and what Caterpillar needs.

Joerg Kumpfert:
I don't know how all the other business units are doing it, but Airbus is working in a global network with universities and research centers and here is a closed network with many partners and here we are in direct contact in order to communicate such requirements, in order also to obtain solutions.

Christian Boller:
How do the other industries see this like the offshore industry or—

Chad Lensing:
Well, I am not sure how people, how people view the offshore industry as high tech, which—that is kind of my feeling with structural health monitoring and all sensors. But I think there are very few of us in the oil industry that kind of, I guess – let me back up here—When I heard about structural health monitoring and I went around our company to ask about structural health monitoring, they all looked at me and go, "We don't do

structural health monitoring." Not even for our haul structures, not even for other subsea equipment and other sorts of equipment that we have used offshore and I think we just don't see this type of industry or community in the oil industry and whether that takes your involvement in making the contacts or networking or going to some conferences that are somewhat oil-related to get the message out there, especially with the technology and information and the results and so we have—My impression is that we have very little contact with the structural health monitoring.

Christian Boller:
Yes?

Nong Chen:
I guess one of the rules we all know is you've got to talk to your customer, but we don't do that often. So I think that is probably one of the golden rules, just have to know what the customer needs. The customer is not like us and the end user. The end user who uses the end user product. So what they really need. I would like to expand examples about the Caterpillar application. Talk about different costs, but it also depends upon what is the size of the structure, what is the application of the structure, who owns that structure. Talking about a multi-million dollar structure, you can easily add thousands of dollars, tens of thousands of dollars. You are talking about a rental machine which is only twenty to thirty thousand dollars and the user doesn't care what happens to it, then it is a very different cost structure and you have to develop a system customized for that application. But the value issue does not impact just one phase of structure. It impacts the design, the operating, how you operate at three spots, and impacts the maintenance, impacts the repair, impacts even the recycling, if you know what the problems have happened in its lifetime, how you actually can recycle it through this cradle-to-cradle concept. And even impact how you bring parts—the logistic part—if you know what has happened to the structure, is going to fail in three months, you might start making the parts when they are really needed and start to reduce the inventory costs. So there are all these applications. I think most engineers are not really into knowing those details, but I guess we have to really get value out of it.

Christian Boller:
Thank you! Any others? Yeah! Please!

Anthony Allen:
Actually there is something, but I think—

Christian Boller:

You are on, Allen!

Anthony Allen:
I guess I will say something welcome before you go! Sorry! One of the things that I guess was commented on in another panel here that I missed, but that somebody forwarded to me was that from a customer point of view sometimes a lot of structural health monitoring—The benefits tend to be at the end of life, which can be far out for a customer. It is hard to see. Is there any way—I know from our networking standpoint where a lot of times it is hard for a customer to see how our networks might benefit them, but sometimes we are able to find other uses for the same devices or networks that are out there. There are other things that it can be used for that maybe are not quite what it was originally intended for, but it helps—it benefits the customer. That may be something that we ourselves really ought to think about, because if you are going to say it is going to benefit me 10 years from now, do I really want to spend a few million dollars when I won't see the benefits for—in some cases, I don't know, that is something to think about as well, but I will have to think.

Christian Boller:
Thank you!

Steve Arms:
I would like to comment—Oh, I'm sorry!

An off-camera panelist:
Go ahead!

Christian Boller:
Right! Let us come to it! Please!

Steve Arms:
I just wanted to say that you know one of the things we have been lucky on is that we have landed some SBIR contracts so that the NSF has funded a lot of the things that we have developed and it is a significant amount of money that the NSF has put into the wireless sensors that our firm can now offer as product. But what that does for us is that it allows us to have a toolbox so that we can reach into and pull out to solve a specific problem for a specific customer.

Christian Boller:
Right!

Steve Arms:
And the deeper your toolbox, the more agile you can be, and the other piece to that is to make your designs modular so the radio, for example, does not necessarily have to be a specific frequency or specific output power. It might be a transmitter or it might be a transceiver. It's a radio. So you put down a radio that is most appropriate. And the sensor-conditional block [?] is another module. You can have a modular approach and you have a deep toolbox. You can solve a lot of problems and keep the development costs to a minimum.

Christian Boller:
Yeah!

Steve Arms:
Thank you! I am sorry to interrupt you!

Christian Boller (turning to someone in the audience):
Yes! And now it is your turn.

Wieslaw Staszewski :
I am Wieslaw Staszewski [the name sounded more like Gaston Fershevsky, but this is the closest name of someone on the list of attendees from the University of Sheffield] from Sheffield University. I can see three clear areas here, subjects in this monitoring business, and there is a community—an academic community involved, providers of the systems, and providers of the products. And it is very difficult for me to see where the links are between these communities, because we have different objectives here. I mean, we academics develop various techniques and publish papers, bring money, get contracts, because this is what we are asked to do. We don't [word missing or unintelligible] these numbers in terms of money, which were mentioned before to provide systems, so we need help from system providers. But you guys who provide the systems, who will do something about this, only will consider markets. If all these big companies like Boeing or Airbus will come to you and will ask you, OK, we will buy the system from you. So the question for me is, OK, do you really want the system and it all goes back to what Professor Park said related to the culture which we have. Do we really have a business case for this system at the moment? You know, I have the impression that many people from industry are coming to this conference just to see what is around. If there is a full system available, you will jump to it today or tomorrow, but because there is no system, nobody wants to put any money into it. The second important comment is there are many people from the aerospace industry here, because there is a lot of money in this sector,

but I think problems are much less than in other sectors. If you go to civil engineering, this is in my opinion where real problems are. All these bridges and buildings, but there is very little money in this area. Could you make a few comments about this?

Christian Boller:
Who wants to start?

Joerg Kumpfert:
I guess I have to comment a little bit. Well, all aero, all main aircraft manufacturers are in difficult times, and there is absolutely no money to be wasted. I think again and again, I think, it is not a 1-step approach. It is as with all technologies a step-by-step approach. And it is possible to mature the individual technologies with comparatively little money to a stage that we can take the next decision, decision gate by decision gate by decision gate in order to minimize the waste of money. To have the approach or the idea in one step—to go from almost zero to a full system, is almost like playing the lottery. I think we don't have money to play lottery. So I would prefer to have the approach to communicate requirements in order to select the different solutions and I think the community is offering quite a bit and quite a lot of different solutions and then to decide on which of these different solutions we are spending more money. This is I think a much more efficient way than to try to go into one system in one step.

Christian Boller:
Thank you! Yeah! All right!

Paul Ruffin:
Someone mentioned earlier about the bottoms up and the top down kind of thing. I like the Doppler model. Doppler is Defense Advanced Projects Agency.

Christian Boller:
Research.

Paul Ruffin:
Doppler. Their model is that they used to have a whole lot of research dollars. You know, a whole lot of money. They still do that. They put out a lot of SBIRs. But they also have quite a bit of research dollars for what they put out on contracts they call broad agency announcements. In those announcements they require that whoever would bid on that would also—You have a better chance of winning if you can come in with a joint proposal with one of the big companies. Also with an endorsement from the military, you know, the Army, Air force, and Navy. That kind of thing also. And that is like the

tops-down, bottoms-up kind of thing. If you have the requirements, I mean, when the proposal goes out with what they are looking for then the customer, you know, could be one of the big companies and the government. They know what they need. Talk about the technology pull. They know what they need. So when you are bidding, you know what the need is. And then—You know what technologies that you are developing to get there and then when you propose—And when you develop the system or develop a technology I should say— it has a better chance of getting to a system when you develop a technology, because the big company has already signed up, the military, the government, also has an interest and then the next question will be, where does it go from it. And they look for the Army, Air Force, and Navy to pick it up from there. The technology, I should say--to put that technology into a system. And it is like the bottoms-up, tops-down, that kind of a thing. So you get the requirements and the early goings and you work on that knowing what the system is going to be in the beginning. And the government endorsements from the beginning.

Abdulrahman Al-Khalidy:

Let me add one thing if I may. As researchers in a company, usually you hate to admit that you have a problem you cannot solve and that you need to go somewhere else to solve the problem. But in fact a lot of times you have problems that really you cannot solve on your own. I think this area is evolving. There are a lot of products and not any given that are mature, they are out there where little help is needed because this is as mature industry, mature component, or a mature system. But there are always new areas where help is needed and I would say there has to be a bridge between academia and industry. I don't know who should reach out first, but I think there has to be more collaboration betweem what's happening in the universities and what's happening in industry. Just to throw this at you, GE has acquired GE Wind, GE has acquired the wind business a few years ago and now they want to go from 2.5 megawatt turbines all the way up to 20 megawatt turbines. And they are talking about turbine blades that are 60 meters in span. This is a huge turbine blade. And there are 3 of them and there are issues with these composites, there are issues with cracks, there are issues with detecting failures and this is a big area for GE. So I am just telling you that this might be an area for some of you who are in that industry to look at.

Nong Chen:

And I would like to echo the previous comment about having a government-funded project, but in this project we are doing I think—and this is probably one where the government agency focuses most on commercialization. So from the beginning when we submit a proposal, some of you have been through that. They have a very strict review process to see what's your potential commercial viability. That also translates to an algorithm. When we are doing a project, we are really under a double pressure of being both technologically successful and also commercially successful. But as a result of that I am hoping that this pressure cooker is actually going to cook something out that is actually going to work for us on a systems level. It is actually going to—it is working very well for us, that putting a lot of pressure on the engineers to think about a business case. In terms of a university, actually we do have two university professors on this project as advisors. Other than picking their brains, I think also because universities are always one of the best and the most open channels for technology definition. They have students and it is basically a free flow of information transfer, so I think I will say we didn't ignore that and they have been very helpful to the project.

Christian Boller:
Thank you!

K.C. Park:
I just want to ask our audience the following question. That is for those of you who have not really participated in the early part of the space program may not remember, but early on after a lot of discussions, so NASA decided to come up with what they call the Apollo Program, a generic kind of roadmap template. After a lot of discussion, a lot bickering in the discussions, so every company, every academic, every centrist, they actually are to adhere to this roadmap template what role they are going to play so that the mission can be accomplished. Do you feel from the industry point of view in developing a generic health monitoring system template so that your company or you as an individual or subcontractor or sense [group?] of developers clearly see the role that you can play in a generic health monitoring template so that more or less there is a consensus what you are doing will fit where and have a clear picture of the role that you could play so that when we communicate and talk about it, we know the reference points where we are really addressing the issues.

Christian Boller:
Thank you very much for that question. I think this is sort of very valuable. We could leave it in the room or, well, maybe there are a lot of statements. My task is just to look at the watch here. Our time is over. And if everybody keeps that question in his or her mind and thinks over it for a year or two years and possibly knows a little better where the role is in the system, I think we have absolutely found out here we have still not a clear picture in that system. That is something I think we need to work on. This is also why I am not going to ask regarding any visions, because I think we should somehow be realistic and that is I think the most essential homework we need to do here. I just want to close this by saying the discussion is not over. It is just over for this time. But if you

can just get to the next figure here. There is a next workshop again where the discussion will certainly continue. This is a process which does not go in one hour and 20 minutes to be solved. Wieslaw Staszewski and myself are going to run the Second European Workshop on Structural Health Monitoring in Munich next year. You are all invited. Most of you should have got obviously already information by email about this, but I realize something did not work completely right. We are going to resend you information regarding this. It is in a very nice place. It is in the German Museum. I think that is the world's oldest technical museum, so a very nice place downtown Munich during a very nice season. You can find also these things on the web. We have a web page on our Sheffield University web page and to the last and even if you take off the extension for the conference which is IWSHM04, you end up on a website which is called EWSHM, and we have just recently implemented thinking maybe to have a sort of virtual platform to communicate the one or the other thing. You may find the one or the other thing which was addressed here. I am thinking of the requirements. I am thinking of the validation. I am thinking of the things like sensors and systems being available. So maybe we can find a sort of virtual home at least to communicate to get information exchange ongoing. I want to close that discussion here, that panel. I don't know if Fu-Kuo Chang is around. Ah! He is here. And I think he is definitely the person who needs to make here an official closure. Thank you very much for the contribution here from our panelists and thank you also from the audience who came out to speak. Thank you! Bye!

Fu-Kuo Chang:

I don't want to say too much because we have run out of time. Thank you for coming to the workshop. I really hope you enjoyed the time staying here over the workshop, and the conversations that we have generated. I hope you will go home and really think about it. In one or two years we will see how the market and the technology have grown. Thank you! Thank you for coming. Bye!